An old bridge transformed into a new one: possible, recommendable?

Diego Carro-López
Associate Professor
Universidade da Coruña
A Coruña, Spain
diego.carro@udc.es

Diego is an experienced researcher in recycled aggregates, sustainable concrete and use of wastes in the construction sector

Ignasi Fernandez
Senior Lecturer
Chalmers University of Technology
Göteborg, Sweden
ignasi.fernandez@chalmers.se

Ignasi works with assessment methods of deteriorated structures and the use of novel materials for a more sustainable building environment.

Natalie Williams Portal
Ph.D. Civil Engineering
RISE Research Institutes of Sweden
Borås, Sweden
natalie.williamsportal@ri.se

Dr. Williams Portal has expert knowledge in experimental and numerical analysis of concrete and interest in fiber-based reinforcement and RCA.

Contact: diego.carro@udc.es

1 Abstract

There is an extensive network of reinforced concrete bridges that give service to roads, highways and railways. These structures where constructed with quality standards of the past, and they suffer of severe problems. Now we consider the idea of substituting them with structural elements with much longer service life. However, there is an important question to be addressed in this area: what to do with the existing infrastructure that would be demolished. Even more if we consider environmental issues.

One good example of this recurrent problem could be found in the case of the Gullspång bridge (Sweden). It was constructed in 1935 and it was severely damaged with corrosion. The administration decided in the 2016 that no further repair would be done and that the bridge would be demolished and one new erected in substitution. A fraction of the concrete from the old bridge was crushed and processed to produce new aggregate. With this aggregate, using the coarse fraction, it was analyzed the structural effect of replacing natural aggregates with these recycled aggregates. The performance of the new structural elements was positive, and it seems that a high percentage of the natural aggregates could be replaced with recycled ones.

Keywords: recycled aggregates, recycling, beam, reinforced concrete, concrete.

2 Introduction

The use of recycled aggregates for concrete production is a growing trend since year 2000 [1]. There are multiple benefits of using recycled materials: 1) to slow down resource depletion at input, 2) to lower pollution at output and 3) to provide a sound growth of worldwide employment. The recycling of construction and demolition waste (CDW) can be an effective method to achieve these benefits. Currently, recycling and re-use of CDW is supported by the European Commission particularly through the Waste Framework Directive [2]

In the case of recycled concrete, it solves mainly two problems. First, the processing of the demolition or construction wastes from the public works. And second, it does not use natural resources. There are different qualities for the recycled aggregates. The higher quantity of concrete that is present in the original waste, the better the resulting aggregates are. On the contrary, if a batch of waste comes with an elevated percentage of impurities such as brick, plaster or asphalt, the aggregate reduces significantly its quality. In this work we used recycled aggregates prevenient from recycled concrete from fragments of beams from a bridge that was constructed in 1935.

There are several recommendations about the maximum quantity of this type of recycled aggregate that can be used in concrete. The majority of regulations define a limit that varies from 20 % [3]. Although some more innovative statutes accept a maximum replacement ratio of 100% of coarse aggregate if the recycled material presents superior quality [1], [4].

2.1 Aggregate consumption and recycling opportunities

The consumption of aggregates is one of the highest impacts of our society. We consume huge quantities of sand and gravel, they come from natural sources or from quarries after crushing. A fraction of these materials comes from recycling in every country of Europe. However, in some of the regions the volumes of recycling are substantially higher.

Table 1. Aggregate production in Europe [1]

	Natural [Mt]	Crushed [Mt]	Recycled [Mt]	Total [Mt]
Austria	63	33	4	102
Belgium	13	46	15	82
Denmark	38	0,2	2,5	48
Finland	34,5	42,8	2	79
France	114	184	21,8	331
Germany	247	218	68	572
Italy	64	89	4	157
Netherlands	43,4	0	18,6	75
Norway	15	70	1,2	86
Spain	20	72	2,2	95
Sweden	12	74	0,5	88
Switzerland	41	5,1	4,9	51
U. Kingdom	50,2	130	54	259
EU28	1036	1223	204	2590

The recycled aggregates could be used for several uses like new aggregates for concrete production, road layers or simply drainage filling of the ground. Each of these uses is valuable, however the most desirable would be to use the recycled material in a high quality use like recycled aggregate concrete. This application implies the compliance with strict quality standard and a long list of chemical and physical tests that the aggregate must pass. The next table shows the available data of recycling in Europe and in context with the principal industrial countries of the world. Some countries like Netherlands and Denmark present a high percentage of recycling. These countries that lead the reuse of aggregates are also the European pioneers of this technology. But there is a powerful reason behind this, they also have in common the relative lack of natural sources of aggregates (natural or from quarry).

Table 2. Aggregate recycling in main European countries and international context [1]

	Recycling of CDW [%]
Belgium	86
Denmark	94
Finland	26
Germany	86
Netherlands	98
Norway	67
Spain	14
Sweden	n.a.
United Kingdom	65
USA	48
Canada	30
Australia	62
Japan	81
Taiwan	91
China	40

3 Recycling beams from 1935

The material used in this research was obtained after crushing beams from a demolished bridge in Gullspång, Sweden. The bridge was originally built in 1935, and due to heavy corrosion damages, it was demolished in 2016. The edge beams were cut into segments for an ongoing research project at Chalmers University of Technology. It is estimated that the beams concrete remains with a compressive strength of 30 MPa and smooth reinforcement bars with end hooks, which are typical for the given construction period. The concrete from the edge beams will be designated as original concrete.

Figure 1. Bridge in Gullspång, Sweden

A portion of the fragments of the beams were available for this other research regarding recycled aggregate concrete. The main idea was to produce reinforced concrete equivalent to the original one; reducing at the same time the environmental impact. This idea was explored in the project that made this research possible, it was named ReConStruct and funded by InfraSweden 2030.

Figure 2. Fragments of the edge beams after cutting

This was an interesting opportunity to analyze real concrete that needs to be recycled. The substitution of an old bridge like this is common due to corrosion of the reinforcement. It seems possible to reuse the old concrete (after crushing) to produce new material for the new bridge beams. Although, this desirable idea is rarely implemented in practice; so there is a need to demonstrate that this should be an option to consider every time that an old concrete structure is going to be demolished.

3.1 Concrete recycling

The beams were processed with a transportable jaw-crusher that produced a recycled aggregate that included coarse and fine fraction. In the following picture, there is also a detail about the magnetic separator that made possible to recover the majority of the reinforcement for recycling.

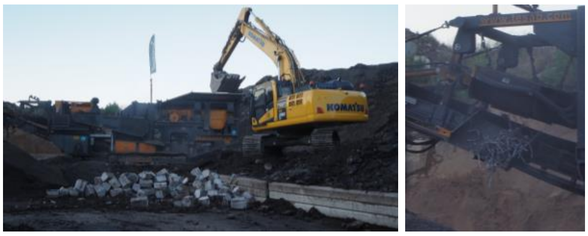

Figure 3. Crushing and separation process

The processed material presented a continuous grain size distribution and it was divided into conventional sand (0/4 mm) and gravel fractions (8/16 & 16/25 mm). In this research we present the results of the application of the coarse fraction (>4 mm) of this recycled aggregate, which is the one recommended in main EU regulations [1], [3].

4 Recycled concrete

4.1 Materials

This research analyses the effect of recycled aggregates in the performance of new beams that include 0 %, 20%, 50% and 100 % of coarse recycled aggregates. To complete the concrete composition, the mixes include natural granitic sand (0/4 mm) and gravel (4/16).

The cement used was a CEM I 42.5 R (compressive strength higher than 42.5 MPa EN 197-1 [5]) very common in Swedish practice. To achieve acceptable workability a naphtalenesulfonate additive was used.

4.2 Mix composition

The reference mixture is presented in the next table. The quantity of cement was of 365 kg per cubic meter, acceptable for aggressive environments. The w/c ratio was of 0.47 and was kept constant for all the coarse aggregate replacement (0%, 20%, 50%, 100%). The procedure to calculate the different mixes was to substitute the volume of the gravel for recycled gravel.

Table 3. Mix composition

Material	Volume [L]	Specific gravity	Weight [kg/m3]
Cement	119.7	3.05	365.0
Water	171.6	1.00	171.6
Natural Sand (0/4)	355.9	2.65	943.1
Natural Gravel (8/16)	347.7	2.62	911.0
Recycled Gravel (8/16)		2.41	
Additive Glenium 5118	5.2	1.10	3.7
Total	1000.0		2394.3

4.3 Water adjustment

The natural aggregates presented a reduced value of absorption, 0.5% for the natural gravel and 0.3% for the natural sand. On the contrary, the recycled gravel presented a value of absorption of 4.1%. This value is low for recycled aggregates and it was reached thanks to the high quality of the original concrete.

The aggregates presented variability in moisture due to the open storage. This simulates the reality of concrete production in industrial plants. However, this made necessary to adjust the water content to reduce the quantity of water added to the mixer considering the initial humidity. Other option that some authors recommend is to not compensate the totality of the absorption, they propose to include only the 80 % of the water [6], [7].

4.4 Compressive strength

The compressive strength was evaluated at 7 and 28 days. The results (mean of three samples) present an anomaly in the 20 % of replacement mixes. These samples exhibited much lower values of compressive strength at 7 and 28 days. This could be attached to the problems with the moisture of a part of the recycled aggregate. This is an important problem that should be controlled in concrete production.

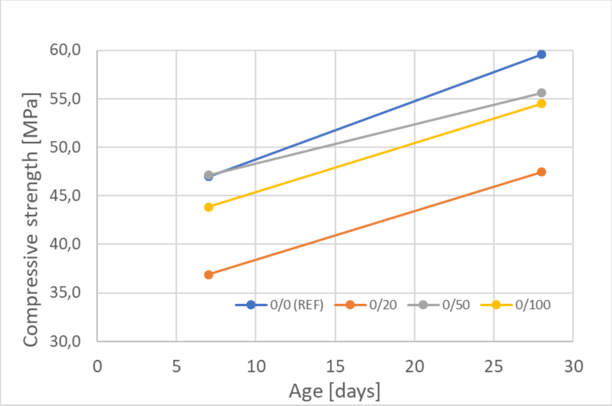

Figure 4. Compressive strength evolution

5 New recycled beams

The original concrete once transformed in recycled aggregates was included in concrete to produce new reinforced beams. These new elements presented a ductile structural configuration with failure by steel. They reproduced the original beams although complying with the modern standards of reinforcement depth and minimum reinforcement. The failure mode was designed to be steel controlled.

We casted beams with incremental percentages of coarse aggregate replacement: 20%, 50% & 100% and 0% as reference. They were tested after 28 days under two-point loading.

The load capacity of the solutions was similar with values of total load around 140 kN. The next figure presents the results of Force vs Displacement test results of two of the specimens.

The beams with 20% of replacement presented identical behavior than those of 0% of replacement. However, the beams with 50% and 100% of replacement presented higher deformation and also a different cracking pattern. It can be observed that the distance between cracks is shorter in the case of 100% of replacement. This also could affect durability of the concrete itself [8] or also to the reinforcement corrosion [9].

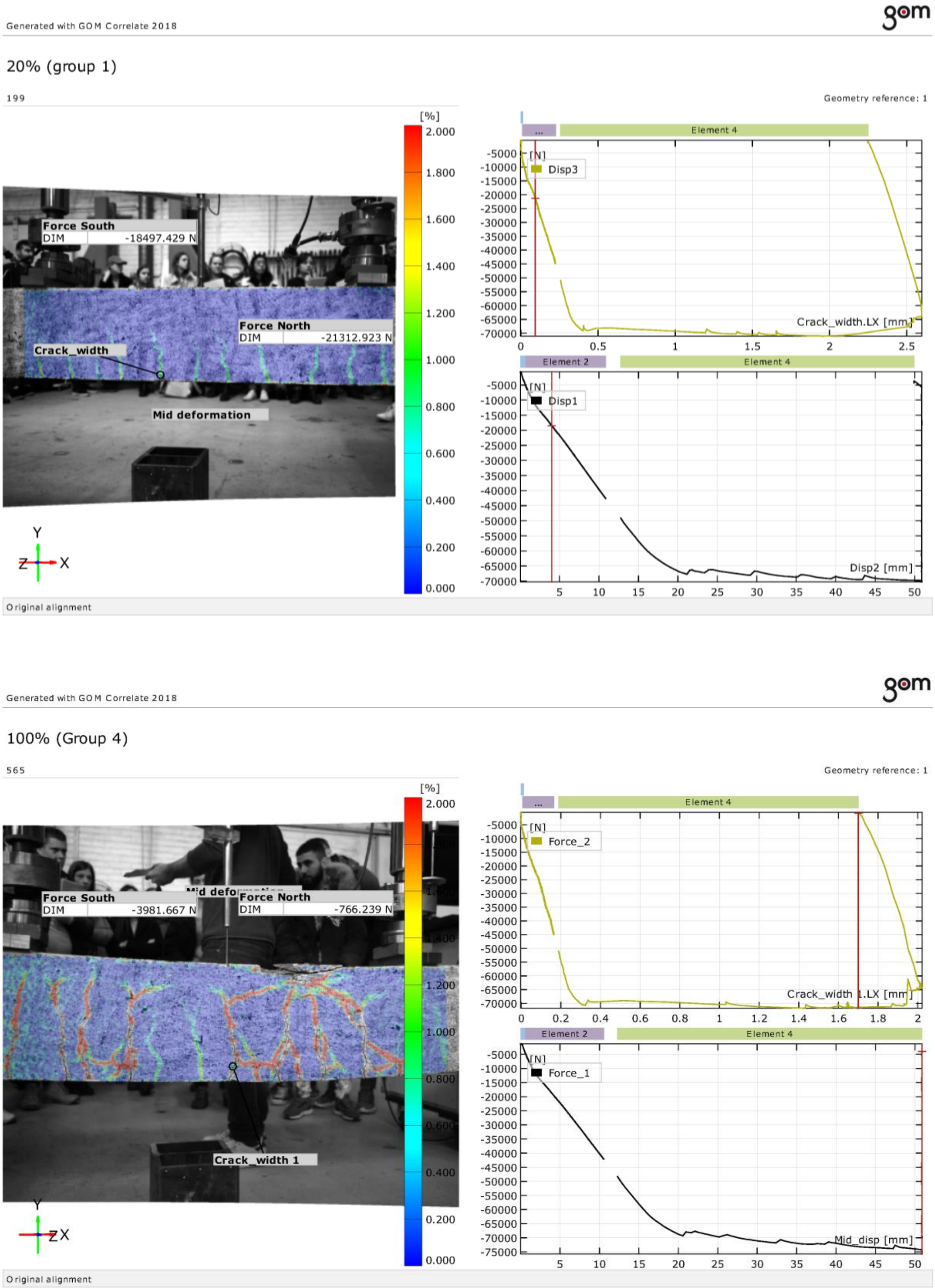

Figure 5. Two-point loading test of the produced beams (20 & 50% of replacement)

6 Conclusions

In this research we have reached the following conclusions:

The use of recycled aggregates is a relevant trend that should be considered to achieve higher sustainability in construction.

The ideal situation would be to reuse the material from old constructions nearby to produce new ones using the recycled aggregates produced locally.

The recycled concrete produced in this research presented a limited reduction of compressive strength.

The beams produced with the recycled aggregate concrete presented acceptable quality even for replacement up to 100%.

If we plan to increase the life service of our structures, one of the factors that we should consider is the use of recycled aggregates in the works. If we plan for better, more resistant and durable structures, we should make them compatible with the sustainability of the resources.

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